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# PLAN OF ACTION AND MILESTONES FOR NAVY COMBUSTION TOXICITY

Prepared for

Naval Research Laboratory
Washington, DC 20375
Ship Damage Prevention and Control (S0384-SL)

Contract No. N00-173-80-C-0125

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This report reviews the Workshop on Toxicology of Combustion Products held at the Naval Research Laboratory on 15-16 October 1980. Participants included U.S. Navy, other government activities, and U.S. Industry. The use of plastic materials has become more prevalent in the design of equipment and in shipboard construction. Use of these materials in quantity can create severe generation of toxic gases

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which can incapacitate or kill personnel in shipboard fires even if they are not in the immediate fire area.

Five major planning areas, along with appropriate tasks, are developed in a coordinated plan of action and milestones for control of toxic products from fires.

The areas are:

- Shipboard sources
- Spread Mechanisms
- Levels of Toxicity
- Levels of Protection
- Requirements and Standards.

The purpose of this plan is to determine and control the effect of toxic gases on surface ship combat readiness.

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# EXECUTIVE SUMMARY


Toxic gas generation from fires can kill or incapacitate shipboard personnel. Recent commercial hotel fires have reemphasized the danger of toxic gas generation by combustible materials. Many of these materials are present in U.S. Navy ships. Since personnel are the most costly and valuable resource aboard a surface ship, it is extremely important that they be provided proper protection from the toxic products of fire so as to prevent their loss or functional impairment.

This report examines the current technical information as provided during the workshop on toxicology of combustion products held at the Naval Research Laboratory on 15-16 October, 1980.

It proposes a conservative step by step program to determine the danger of shipboard toxicity and then provides means to passively or actively protect personnel.

The report also examines methods of implementing the program within the current U.S. Navy R&D program structure.

## Introduction

This paper reviews the current state-of-the-science of combustion toxicity as presented at the "Workshop on Toxicology of Combustion Products" held at the Naval Research Laboratory (NRL), Washington, D.C. on 15-16 October, 1980. Application of this technology to Naval surface ships is examined in order to develop a realistic plan of action and milestones for Navy program implementation. Identified items are presented in the form of a statement of work to be accomplished and a logical progressive order of planned action. Since the subject matter involves the participation of a number of Naval R&D activities, coordinated mangement options are addressed. The proceedings of the Workshop will be published by the NRL. A summary is attached as the Appendix.

## Shipboard Fire Discussion

Fires aboard Navy ships reduce combat readiness through the destruction of equipment, incapacitation or loss of personnel, and the off-line loss of a major offensive/defensive unit. During the Second World War, about 50 percent of destroyers damaged by above water explosions had to combat resultant fires. The greatest shipboard fire problem in World War II was caused by the Kamikaze hit(s) which enveloped the area of impact with an intense and widespread gasoline fire. This type of hit would be equivalent to today's cruise missile threat and would cause shipboard plastic materials to burn, generating toxic gases. Generally the loss of carriers during World War II was due to progressive fire or fire related incidents. Major peacetime carrier fires have resulted in loss of personnel and reduced operational capability. Fires aboard destroyers had to be controlled before any action was taken on flooding. Failure to control the shipboard fire within a short period of time

led to the loss of the ship.[1]

Fire on a Navy ship has to be fought in close quarters using installed equipment and trained personnel. There is no convenient way to vent fires on Navy ships due to the nature of ship construction, and the fire action often requires personnel to access directly into the fire. During the fire fighting action, the ship must remain functional in order to accomplish its mission with available equipment and personnel. After a successful fire fighting action, sufficient repair and operational personnel are needed to return the ship to a combat readiness condition.

Present day surface ships in a modern war bring new dimensions to the hazards of fire by reducing combat readiness of embarked personnel. Surface ships contain over 300 types of different materials, many of them consisting of plastics which may produce highly toxic gas combustion products, such as carbon monoxide (CO), hydrogen cynaide (HCN), hydrogen cloride (HCl) and carbon dioxide ($CO_2$). Large warhead cruise missiles impacting a modern ship will invariably result in a fire and subsequent production of toxic gases. These toxic products are present in combustion smoke (consisting of gases and suspended particles) which immediately affects the respiratory system and reduces visual capability. Off-gassing of toxic materials may also result from incipient burning (gradual decomposition) common in overheating electrical or electronic equipment. Due to the nature of ship design and ventilation systems, this smoke can spread into non-fire areas at significant distances from the source.

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[1]War Damage Report No. 51, Preliminary Design Section, Bureau of Ships 25 January, 1947.

Exposure of humans to CO, HCN and HCl gases can result in death or incapacitation. The effect of CO on humans is shown in Table 1 as an example.

TABLE 1
EFFECT OF CO ON HUMANS

| Effect | CO Concentration (ppm) |
|---|---|
| Permissible for an exposure of 8 hours | 50 |
| Concentration which can be inhaled for 1 hour without appreciable effect | 400-500 |
| Concentration causing a just appreciable effect after 1 hour of exposure | 600-700 |
| Concentration causing unpleasant but not dangerous symptoms after 1 hour of expsure | 1000-1200 |
| Dangerous for exposure of 1 hour | 1500-2000 |
| Fatal in exposures of less than 1 hour | 4000 and above |

Recent examples of death by toxic gases are the MGM Hotel fire in Las Vegas, Nevada, and the Stouffer's Hotel fire in New York; over 100 lives were lost in these two incidents. Personnel were trapped in an area not burned by the fire, but they were exposed to toxic gas resulting in disorientation, incapacitation, or death. Another incident occurred in a commercial airliner in which the fire originated in the rear lavatory and was contained, but not extinguished. Of the 134 passengers on board, 123 persons died due to toxic gas inhalation. The plane was landed safely. The purpose of the program outlined in this POAM is to determine the potential for a similar disaster aboard Navy ships and, if the threat exists, what steps must be taken to eliminate it.

The manning on Navy ships today depends on a limited number of highly skilled maintenance and operational personnel that are required

to remain in designated spaces as long as possible to continue combat operations. After damage is brought under control, they must be available to reman and repair the ship in order to restore combat readiness. Protection of human life is a critical element of combat readiness. Generation of certain toxic gases even in a limited quantity, will affect the nervous system, visual acuity and motor function of a highly skilled operator or technician and could result in personnel taking incorrect action or delayed reaction.

## Statement of the Problem

The problem is to determine the allowable amounts of potential toxic gas material in critical spaces on ships and to define the performance decrement of personnel subjected to toxic gases in order to determine the best means to maintain ship combat readiness. The purpose of the POAM is to provide a solution to the problem.

## Major Planning Areas

There are definable functional areas which must be established to develop the overall POAM for U.S. Navy toxicology program initiatives. These will then be divided into defined work tasks which will support that planning function and interface with other work efforts. These tasks will examine in logical sequence the source of toxicity in the form of materials, the toxic potential of these items, the possible spread of toxic gases on a surface ship, the effects on personnel performance degradation and the methods to protect personnel. The toxicity hazard may be controlled by judicious use of materials, monitoring of designated spaces and control of the spread mechanism by requiring a level of personnel protection or combinations of each. A key objective of the POAM is to develop information and establish a data base that will determine

degradation of combat readiness due to personnel exposure to toxic gases and to establish design specifications and shipboard procedures to minimize the toxic effects.

The main planning areas are:

- Shipboard sources
- Spread mechanisms
- Levels of toxicity
- Levels of protection
- Operational requirements and MILSTDS

These major planning functions described are structured to take advantage of current knowledge and data and then to expand both the knowledge and data base to provide an increased level of shipboard combat readiness.

A. Shipboard Sources

The fundamental question is, "are there sufficient amounts of potentially toxic material in areas subject to fire that would pose a serious problem to personnel?" These materials could be inherent in ship design such as insulation material, paint, cabling and electronic encapsulants. The material could be brought aboard ship either by personnel or as packaging material for consumable and nonconsumable stores and spare parts. Use of certain procedures and chemicals in maintenance, cleaning and fire fighting could also contribute to the basic toxicity potential.

B. Spread Mechanism

If potentially toxic substances are generated in a fire, can these materials spread from one area of the ship to another? If so, then the spread mechanism assumes an important function. The spread mechanism can vary depending on material condition of readiness set on the ship.

C. Levels of Toxicity

If enough toxic gas producing materials are available and can

impact on critically manned areas, what levels of toxic products are acceptable to provide assurance that the performance of personnel is not reduced by overt or covert sensory impairment?

D. Levels of Protection

Given current shipboard personnel protection procedures, what additional equipment, if any, is needed to allow personnel to safely remain or to re-man critical combat areas?

E. Operational Requirements

Establish exposure limits for personnel in critical spaces. Revise MILSTDS to provide clear and adequate toxic gas generation protection.

Work statements under areas A-E are developed in the POAM to allow the Navy to proceed in a logical manner in determining what would be the most effective way to reduce the hazards of toxicity during shipboard fires.

Statements of Work

The recommended combustion toxicity program provides a means to organize existing data, obtain new and relevant data and provide resulting control procedures such as operational requirements and technical standards and specifications. The following statements of work provide a scope of the effort to be performed and specific tasks to be accomplished. An overview of the recommended program is provided in Figure 1 and is the plan of action and associated milestones.

## A. SHIPBOARD SOURCES

### A-1. Survey of Shipboard Sources

Introduction: This work will investigate the materials currently on a selected ship class in order to document the location of material aboard ship. It will address permanently installed materials and items stored for a combat load.

Scope of Work: From ship class plans and selected on-site inspection, a determination of the density of consumable materials will be made by compartment from the ships combat load. The amount of potential toxic consumables and their designated shipboard location will be identified. Based on data supplied by Navy Safety Center and Condition I manning, a list of spaces containing toxic material, probability of fire and personnel density will be provided.

Task 1: Survey a selected class ship for location and amount of potentially toxic material in cables, ship construction, painted surfaces, nonmetallic flooring, bulkheads, overheads, habitability items and electrical and electronic components.

Task 2: Survey the compartment combat loading consumables for potential toxicity such as fuels, packaging, paint, cleaning solvents, chemicals, spare parts, etc.

Task 3: Establish weighting criteria to identify those spaces where the probability of toxic gases affecting personnel are critical. Minimum criteria are: weight of combustible material, volume of combustible material, compartment personnel manning, compartment volume, ignition sensitivity, toxic gas potential, and potential transfer mechanisms.

Task 4: Provide a list of critical spaces and types and amount of toxic material available in each critical space.

Task 5: Provide recommendations for use in Task A-4 (MILSTDS)

Task 6: Develop a systematic approach for use on other classes of ships. (Task A-2, A-3)

A-2. Survey of Second Class Ship Toxic Material Configuration and Potential

A-3. Survey of Third Class Ship Toxic Material Configuration and Potential

These tasks will be similar to task A-1, and will use the methods developed by Task A-1. The procedures developed in Task A-1 could be refined for later tasks reducing the time and dollars required.

A-4. Determine Amounts and Types of Toxic Gases Generated by Shipboard Material

Introduction: This work will establish the amount of potentially toxic gases generated by the decomposition of material that can be hazardous to personnel.

Scope: This task will use existing data to catalog the amount and nature of toxic gas generated by decomposition. It will distingush the amount of toxic gases by the following burning stages: incipient, smoldering, flaming, and heating. Where data is either unavailable or inconclusive, tests, using established practices, will be conducted to supplement the data base as needed.

Task 1: Document published type and amounts of toxic gases released by burning of a standard amount of material(s) likely to be found on a U.S. Navy ship. Catalog amount of gas in relation to burning stage.

Task 2: Establish standard relevant tests to determine the amount and type of toxic gases by burning method.

Task 3: Provide recommendations for the revision of MILSTD 1623C (SH) electrical and electronic MILSTDS in order to establish toxicity limits for onboard material concentrations in spaces.

## B. SPREAD MECHANISMS

### B-1. Assessment of Spread of Toxic Gases Aboard Ship

Introduction: The purpose of this work is to identify and document the various means that toxic gases can be generated and spread throughout a ship by the performance of installed equipment, ship construction and current shipboard procedures involved in fighting and suppressing shipboard fires.

Scope: Installed shipboard ventilation equipment, bulkhead and overhead access and penetration areas will be reviewed using ship plans and verified with a ship inspection. Damage control procedures under battle conditions will be reviewed to identify the possibility of generation of toxic gases or their movement by shipboard damage control procedures.

Task 1: Provide a schematic diagram of air volume flow to critical ship spaces. Identify current procedures and methods as to how this is controlled or modified under various material conditions.

Task 2: Review ship fire fighting procedures to evaluate in what manners they may increase the production or spread of toxic gases from one area of a ship to another.

Task 3: Provide recommendations for the detection and removal of toxic gases/smoke from one area of a ship to another and methods or techniques to control generation and spread of toxic gases by current or new damage control procedures.

Task 4: Based on the results of Task 3, address the applicability of recommended techniques to all classes of surface ships.

# C. LEVELS OF TOXICITY

## C-1. Maximum Allowable Concentrations of Toxic Products

Introduction: The purpose of this work is to establish maximum allowable concentration (MAC) values for smoke from specific material aboard ship. Impairment of escape will generally be the primary consideration in establishing these values. However, in critical areas where continued manning of duty stations is essential, the potential of the smoke to produce a serious decrement in performance will be the principal determinant of the MAC value.

Scope of Work: This work will utilize existing data to determine concentrations of smoke and toxic gas from designated shipboard materials and duration of exposure that will impair escape from the fire environment or reduce personnel effectiveness. When a relevant data base is not available or needs expansion or verification, the necessary experimentation will be implemented.

Task 1: Review laboratory bioassay data and large-scale test data, when available, for relevant materials to determine primary toxicants of combustion mixtures. When adequate data are available and primary toxicants are CO and/or HCN, MAC values of the smoke will be established on the basis of known CO and HCN concentration-time functions.

Task 2: Validate relevance of laboratory bioassay animal model and incapacitation endpoints for extrapolation to man. If present methodology is inadequate, an appropriate laboratory bioassay will be developed. Verify the results of the bioassay by comparison with large or full-scale fire tests of materials and mixtures of materials.

C-2. Toxic Product Interaction

Introduction: The purpose of this work is to establish maximum allowable concentration (MAC) values for mixtures of toxic gases and the effect of stress factors. Impairment of escape will generally be the primary consideration in establishing these values. However, in critical areas where continued manning of duty stations is essential, the potential of the smoke to produce a serious decrement in performance will be the principal determinant of the MAC value.

Scope of Work: This work will utilize data obtained from C-1 to determine concentrations of smoke from applicable combinations of materials and duration of exposure that will not impair escape from the fire environment or reduce personnel effectiveness. When a relevant data base is not available or needs expansion or verification, the necessary experimentation will be implemented.

Task 1: If relevant data is not available for materials with high fire impact in critical areas, conduct laboratory bioassays to identify highly toxic combustion mixtures. Establish five minute $IC_{50}$ values (the concentration that incapacitates 50 percent of the animals in five minutes) to enable estimation of MAC value for man.

Task 2: Determine interactions of irritant gases such as acrolein, HCl and HF with the primary toxicants of combustion mixtures (CO and HCN) in causing incapacitation and performance decrement.

Task 3: Utilize or develop, if necessary, appropriate animal model and methodology for measuring the potential of smoke from representative materials to affect human performance. Functions that should be measured include reaction time, motivation changes, discrimination, motor coordination, memory, visual acuity, and other actions needed to be taken

during an emergency. Analysis of combustion products should emphasize the threshold concentration producing behavioral changes, the elapsed time to the onset of the change and the duration of action following the termination of exposure. An alternative approach, the use of human subjects, will be considered and may be necessary.

Task 4: Investigate interaction of stress factor with smoke inhalation to determine whether toxicity is altered by stress and to what extent.

## D. LEVEL OF PERSONNEL PROTECTION

### D-1. Determine Current Navy Capability to Protect Personnel From Toxic Gases

Introduction: This task will determine if personnel protection equipment is adequate for toxic gas protection. It will investigate sensitivity of alarm devices, breathing apparatus and smoke control mechanisms.

Scope of Work: Identify standard shipboard equipment that could be used for detection of CO, $CO_2$, HCN and HCl. Investigate the use of current shipboard emergency breathing devices and their ability to protect key personnel from toxic products. Investigate smoke control devices planned or currently in use to remove or control smoke ingress to critical spaces.

Task 1: Review test work currently being performed by the U. S. Navy on fire detection sensors to determine capability to detect toxic products both as to content and density.

Task 2: Review test data and conduct necessary tests on shipboard portable breathing apparatus as to capability to allow critical personnel to remain at key stations. Determine:

Degree of protection against (CO, $CO_2$, HCl, HCN)
Duration of protection
Availability of devices
Polluted atmosphere independence.
Potential of auxiliary air supplies

Task 3: Review current shipboard smoke control procedures to determine applicability. Included are:

Installed vent control
Smoke supression
Alternative sources of venting

Task 4: Prepare recommendations as to modifications required for existing shipboard equipment to reduce personnel hazard to toxic gases in key areas. Identify areas where new initiatives are required.

D-2. Personnel protection requirements and development.

Introduction: Based on the survey and recommendations of Task D-1 and C-1. establish personnel protection requirements for key spaces. Provide recommendations for development and design of new equipment to meet these requirements.

Scope of Work: The modification of sensors, protection and smoke control devices may not provide adequate protection. This task will define areas of new initiatives and devices that are within the state-of-the-art that could be readily adapted for U. S. Navy use.

Task 1: Review equipment products and procedures currently being used in civilian industries with comparable toxic gas control problems (i.e, Bureau of Mines) and evaluate their adaptabilities for Navy use. Examples of such items are:

- Pressurized breathing apparatus
- Long staying time breathing apparatus
- Toxic gas concentration detection systems
- Pressurized areas for smoke control
- Emergency smoke venting or isolation
- Gas mixture breathing systems

Task 2: Based on previously developed information, provide standards and specification requirements for personnel protection against toxic gases in designated shipboard areas.

# E. REQUIREMENTS AND STANDARDS

## E-1. Requirements And MILSTD Revisions

Introduction: The purpose of this task is to develop operational requirements for material loading and critical ship areas to insure that maximum allowable concentrations (MAC) of shipboard toxic gases are not exceeded. MILSTDS and MILSPECS will be revised and reviewed to modify material concentration and density in critical spaces.

Scope: This task will determine reasonable limits for the exposure of personnel required to operate in critical spaces where a high probability for the presence of combustion toxicity would exist in combat fires.

Task 1: Develop an operational requirement for the protection of shipboard personnel when subjected to toxic gas products. This requirement will specify limits of selected material to be used in shipboard environment. It will establish an upper limit for the amount of toxic gas to which personnel should be subjected to and specify criteria for warning and protective devices needed if this level is exceeded.

Task 2: Provide specific recommendations to revise MILSTDS for ship material design composition of disposable packing material and crates and for material used for insulation and components of electrical and electronic systems.

## POAM IMPLEMENTATION

The technical actions described involve a number of organizations of the Navy R&D community. Some of these actions could be addressed as part of a damage control R&D program. The selection and use of material aboard ship comes under the jurisdiction of Naval Sea Systems (NAVSEA) and to a large extent consumable packaging, stowage and shipboard load levels are under the cognizance of Naval Supply System (NAVSUP). Toxicity experiments are under program element 61153N at the Naval Medical Research and Development Command. Fundamental research on combustion processes is conducted by the Naval Research Laboratory (NRL). The execution of this recommended POAM will require action by at least all of the above mentioned activities and possibly others not yet identified. Some of the action items indicated are interdependent and would require results of the action to be provided to other activities. A large amount of the information needed to determine the answer to surface ship fire toxicity is available in the open literature and held by other government and industrial activities and should be used in implementing the plan to reduce overall research and development costs to the U.S. Navy.

Program funding under each R&D organizational element must be coordinated as a central program to avoid picemeal results and resultant non-viable products. Coordination could be at the Naval Material Command (NAVMAT level since NAVSEA, Director of Naval Laboratories (DNL), NAVSUP and Bureau of Medicine (BUMED) are involved. A program sponsor at the Chief of Naval Operations (OPNAV) level should be designated to coordinate these efforts and support the program in the POM.

The shipboard fire toxicity program would require that each program element should be recognized as part of the total program and not an individual item, and as such, block funding should be used. A priority for the entire program should be established and each element should reflect that priority. The program plan should be supported by CNO (OP-03) in POM 83 with each R&D organizational element submitting a coordinated work package.

An alternative to central program planning would be to reach agreement on this report and allow each individual R&D activity the responsibility for accomplishing the action item within existing and future budget projections. This can be accomplished by an ad hoc committee as a subset to an existing NAVMAT survivability committee, or under the NAVSEA Damage Control Program. The risk involved in this method is the delay of the plan in time and a reduction in total cost effectiveness for the U. S. Navy. Committee organization traditionally causes time delays and increases overall cost.

Another alternative is to assign a system support contractor/consultant or Naval laboratory to oversee and coordinate the technical aspects of this plan and act as a liaison to the ad hoc committee. This approach would not, however, insure that the funding or program elements would remain intact, but would provide a dedicated entity working under the committee to insure that important tasks are accomplished.

The fourth alternative would be a combination of the three previous alternatives:

| | |
|---|---|
| OP-03 Coordinator | POM Responsibility<br>6.3.6.4 Funding Elements |
| CND Coordinator | Funding Responsibility<br>61., 6.2 |

| | |
|---|---|
| Ad Hoc Committee | NAVSEA/NAVSUP/BUMED/NRL. Under NAVSEA survivability chairman with OPNAV participation. |
| Contractor/ Consultant or Naval Laboratory | Technical support coordination |

This alternative is considered to be the most practicable because it does not create new organizations but requires existing organizations to work together. It also recognizes toxicity as a part of the ship survivability program.

# APPENDIX

## Purpose of Workshop

The stated purpose of the Workshop on Toxicology of Combustion Products is to examine toxicity hazards that are relevant to Navy fires and to determine what information is currently available from combustion toxicity studies in the civil sector that could impact the shipboard fire problem.

## General Results of the Workshop

The workshop agenda included discussions of the U.S. Navy's experience with fires on shipboard and methods employed to prevent or minimize such fires, plus assessments of toxicity risks. The conclusions are to be used to identify areas in which further research is needed to reduce the hazards posed by toxic combustion products in shipboard fires. Speakers and participants represented the following organizations:

### U.S. Navy

Board of Inspection and Survey
Chief of Naval Operations
Commander, Operational Test and Evaluation Force
Naval Education and Training Center (NETC)
Naval Material Command
Naval Medical Research Institute
Naval Research Laboratory
Naval Safety Center
Naval Sea Systems Command
Naval Ship Research and Development Center
Naval Submarine Medical Research Laboratory
Naval Supply Systems Command
U.S. Navy Damage Control School

### Other Government Activities

Central Intelligence Agency
Federal Aviation Administration
National Aeronautics and Space Administration
National Bureau of Standards
National Science Center (NSC)
U.S. Coast Guard

## Industrial Activities

Southwest Research Institute
Midwest Research Institute
Johns Hopkins University, Applied Physics Laboratory
Hamilton Standard
McDonnellDouglas Aircraft
DuPont de Nemours Chemical Company
Vector Research
BETR Science, Inc.
Haskell Laboratories
Armstrong World Industries
International Union of Toxicology

## U. S. Navy Highlights

The following are highlights of presentations of Naval speakers concerning the activities currently related to surface ship fire combustion toxicology.

- Selection of materials for shipboard use as specified by MILSTD 1623C (SH) does not specify toxicity criteria.
- Fire is the greatest threat to a ship. During the period from January, 1975 to September, 1980, a total of 718 fires were reported on Navy ships. Total costs of these fires were approximately $33M. In addition to the cost of these fires, a total of 1258 ship operating days were lost, three personnel died, and 113 persons were injured or incapacitated. These fires originated during peacetime operations.
- Major causes of fires were electricity, open flames, flammable liquids or gases, with electrical fires accounting for 280 of the 718 fires.
- Fire prone spaces are those in which material and source of ignition is prevalent and where personnel errors or material failures occur.

- No data was available in major weapon induced wartime fires, but periodically a major fire occurs aboard carriers causing significant damage and loss of life.
- The U. S. Navy has special breathing apparatus to be used by firefighting personnel. (OBA)
- The U. S. Navy provides a special breathing apparatus for individual escape from spaces threatened by fire.
- Fires are most likely to occur in enginerooms, storerooms, machinery rooms, and habitability spaces.
- Peacetime deaths aboard ships attributed to fires is small with the exception of sporadic larger carrier fires. The injury/incapacitation rate of personnel during and after the fire is significant.
- No specific toxicology program exists within the U. S. Navy to address fire combustion toxicity aboard surface ships.

Smoke Toxicity Highlights

Presentations on smoke toxicity were divided into two subject areas, Toxicological Effects of Smoke Inhalation and Assessment of Materials and Systems Smoke Toxicity Risks. The following are highlights of these presentations.

- From a detailed investigation of 463 fire-related deaths in the state of Maryland during 1972 to 1977, the primary cause of 76 percent of the fatalities was toxic gas inhalation. Analyses of the blood of these victims indicated that CO and HCN were the principal toxic gases. Additionally, high concentrations of inorganic metals (lead, antimony and others) and of absorbed pulmonary irritants (aldehydes and hydrocloric acid) were detected in the trachea and lung tissues.

The latter combustion products may contribute significantly to delayed fatalities from smoke inhalation.

- Mixtures of combustion products generated in Navy shipboard fires are very complex due to the variety of fuels, structural materials and armaments that may become involved. Acute effects in personnel exposed to these mixtures may result in sensory irritation, anoxia, performance impairment, incapacitation, neurotoxicity, and death. A satisfactory model for prediction of hazards of these mixtures must consider the toxic interactions of the components of these mixtures.
- The widespread use of synthetic polymers in construction materials has emphasized the need for identifying the toxic combustion products of these materials and for determining their potential toxicity. For most polymers, CO is the principal combustion product responsible for acute lethal effects. For nitrogen-containing polymers, HCN is the principal toxic component of the combustion mixture. In some cases such as combustion of PVC, large quantities of HCl are emitted which can produce acute lethalities.
- Smoke from all polymers contains sensory irritants which result in impaired vision and breathing and can impede escape and/or incapacitate personnel. An animal model has been developed which evaluates the sensory irritating properties of smoke from polymers by measuring the decrease in respiratory rate induced by the irritants. This model can be used to rank materials on the basis of the irritating properties of their smoke.

- The most commonly employed indicies of toxicity for evaluation of the combustion products of materials have been the $LC_{50}$ (the concentration of smoke that kills 50 percent of the animals) and the $IC_{50}$ (the concentration of smoke that incapacitates 50 percent of the animals). Since time is a major factor in escape from the fire environment, the $LT_{50}$ and $IT_{50}$ (the time at which smoke kills and incapacitates, respectively, 50 percent of the animals) are receiving increasing emphasis in evaluating the potential toxicity of the decomposition products of materials.
- The principal uses of small-scale laboratory bioassays are to identify materials with highly toxic combustion products and to enable a comparison of the toxicities of materials when combusted.
- The necessity of verifying the results of representative small-scale laboratory bioassays with large-scale tests is well recognized, but limited studies have been conducted to date. In one such comparison test conducted by the NBS, the $LC_{50}$ of a large-scale test of polyurethanes was almost twice that determined by the laboratory bioassay. Concentrations of some gases, CO, HCN, and $CO_2$, were comparable in the two tests, but the concentrations of other gases differed. More comparative testing is necessary.
- With inhalation experiments of defined atmospheres such as CO and HCN and the use of the rat as a surrogate for humans, the data can be used to derive concentration and time of exposure functions that are predictive of incapacitating and

lethal doses in man. These functions may have limited value when other toxic gases are present in the combustion atmosphere and, particularly, when strong irritants are present.

- Time-to-death measurements in laboratory bioassays do not produce the same ranking of materials' relative toxicity as time-to-incapacitation measurements. Therefore, if time-to-incapacitation is the important element in survivability, lethality data cannot be used to generate a meaningful relative ranking of materials' toxicity.
- Tenability limits of common smoke toxicants were discussed and a method of estimating these limits for the more common toxicants was presented. The tenability time (TL), also referred to as hazard limit (HL), may be defined as the maximum concentration which would permit a person to escape from a threatening fire environment before succumbing.
- The use of cardiac arrhythmias as an index of incapacitation in toxicity evaluations of combustion products of materials was described. Other methods in common usage in small-scale bioassays are the rotating wheel, the rotorod and leg flexion. These measures of incapacitation of the rat in laboratory bioassays must be verified by appropriate large-scale tests with nonhuman primates before laboratory bioassays can be used to predict the toxicity of materials in full-scale fires.
- In some circumstances, particularly during combat, evacuation of personnel from critical areas of a ship because of the presence of limited smoke may not appear necessary. However, inhalation of certain smoke gases may result in impaired performance even though toxic symptoms are not apparent.

- Relative toxicity of a material should not be confused with the relative toxic hazard of that material. The conversion from the relative toxicity to the relative toxic hazard of a material requires consideration of the quantity of the material in its application. Also, toxic hazard is only one of many parameters that make up the overall fire hazard of a material. Other parameters that are an integral part of the fire hazard are ignitability, rate of flame spread, heat release and smoke production.

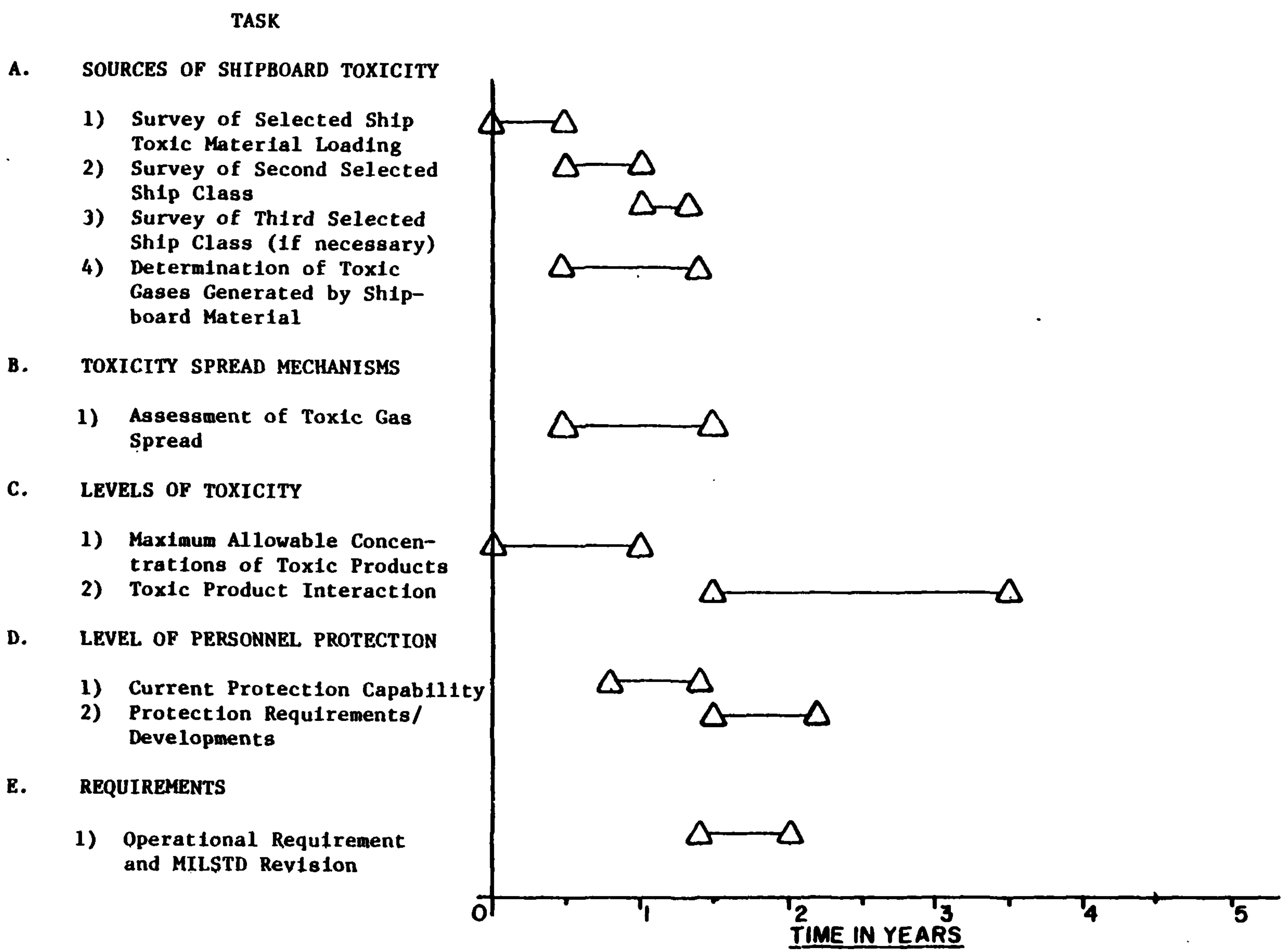


FIGURE 1. PLAN OF ACTION AND MILESTONES - SHIPBOARD FIRE COMBUSTION TOXICOLOGY

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